Integrated Geobiology and Microbial Ecology Research in support of NASA's Exploration:

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Overview: As NASA seeks to understand how life evolved on Earth and to search for evidence of life elsewhere in the universe we must be able to distinguish in the rock record what characteristics are clear indicators (biomarkers) for the presence of life. On Earth we know that early life was microbial and that these pervasive microbial ecosystems had profound impacts on the development of our atmosphere, biosphere and the evolution of many metabolic pathways. Yet even in this case where microbial life had a dominant role in the co-evolution of the planet and it's associated biosphere, clear signs of microbial presence in the rock record are often difficult to identify and interpret. Though difficult, the need for biomarkers is essential, and thus requires continued research that incorporates novel approaches to expand our understanding of the subtle traces of life in the terrestrial and extra-terrestrial record. This work calls for a highly interdisciplinary approach linking classical microbial ecology, geology, and molecular biology in both natural ecosystems and in recently developed experimental facilities where ecosystems of relevance can be simulated, yet allow for specific research control of individual environmental variables such that environmental feedback controls on microbial structural and metabolic responses, mineralization and biomarker production can be rigorously tested.

Key Targets of a Geobiology/Microbial Ecology Initiative:

1) Understanding the processes by which complex microbial ecosystems interact with their environments to create a wide-array of complex 3-dimensional shapes and textures in non-mineralizing (microbial mats) and mineralizing (biogenic stromatolites, microbialites and mineralizing biofilms) structures.
2) Specifically linking what information (macrostructure, microstructure, mineral type and distribution, lipid biomarker, isotopic signatures) the various types of structures can conclusively tell us about what types of organisms and environmental conditions formed them.
3) Tracking which of these diagnostic clues that microbial processes were responsible for formation of a structure, persist and remain recognizable after the living biomass has decayed.

Approach to addressing targets: Ongoing geobiology research at the microbial ecosystem structure laboratory, focuses on linking detailed field environment and microbial distribution characterization at sites where mineralizing stromatolites and microbialites are actively forming in a) intertidal and hypersaline basin environments in the Bahamas, b) high altitude – Mars Analog lagunas in Bolivia, c) low altitude lakes with active microbialites in Kryzgistan, and d) hypersaline microbial mats in Baja, Mexico. We document overall community structure, with added emphasis on documentation of cyanobacterial distribution as these microbes are largely responsible for development of structural scaffolding which affects distribution of other microbial groups.

Detailed analyses and observations lead to construction of a library of linked potential biomarkers and environmental conditions as well as specific hypotheses regarding structure formation mechanisms, and biomarker content in each of these types of environment. In order rigorously test these hypotheses we have developed an Ecosystem Simulation collaboratory at NASA Ames research center. Here, long-term experiments are conducted to monitor complex ecosystem responses (including shifts in biogeochemical cycling pathways, onset or inhibition of mineral formation, changes in 3-dimensional community structure, biogenic gas production, lipid biomarker production, and community population shifts as assayed by molecular techniques) to specific controlled environmental conditions or perturbations.

These techniques greatly complement traditional laboratory and field assays which, though providing important information, are limited in providing realistic environmental conditions or the ability to manipulate environmental factors in order to test hypotheses. By using all three methods in consort (field documentation, classical laboratory isolation – experimentation and finally relevant experimentation under realistic yet controlled environmental conditions of sunlight, water flow and chemistry) we can more completely and quickly assess, understand and most importantly, learn to recognize the biosignatures of life in the rock record.

Relevance to Exploration Science: Among NASA's imperatives are a necessary requirement to further our knowledge of how the physical and chemical properties of terrestrial environments have interacted with biological components to shape the biosphere of Earth. This is of critical importance, not only to understanding how life arose on Earth, but also, and even more importantly, in guiding our exploration missions. As we now know that the conditions prevailing on Mars were comparable to Earth's at the time when life developed this fact becomes a compelling first guideline to structure our search strategy on Mars. There is no certainty that putative life on Mars would have been comparable to terrestrial primitive organisms; but the level of similarity of basic chemical building blocks and environments allows for the possibility that life could have arisen in a similar forms on both planets to be our best viable working hypothesis. As NASA's future exploration goals require that we learn how to interpret and distinguish between structural or chemical patterns in the rock record that develop by abiotic means from structural or chemical patterns that develop when life is introduced into the system, future expansion of integrated geobiological studies will be instrumental to achieving these scientific and mission goals.